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SILVER-ZINC BATTERIES, (U)

JUN 65 R COSS, J DENSON

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by

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J./Denson



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SILVER-ZINC BATTERIES

1. INTRODUCTION

Until about a decade ago, only lead-acid storage batteries were utilized as a reserve source of dc power for aircraft applications. However, technological advances in the alkaline family of batteries have introduced new electrochemical systems having significant advantages over the lead-acid battery. One of these electrochemical systems is the silver-zinc battery.

The silver-zinc battery derives its name from its active materials, silver-oxide (AgO) for the positive electrode and porous zinc metal (Zn) for the negative electrode. The electrolyte is a liquid solution of potassium hydroxide (KOH) in distilled water.

The silver-zinc battery has two particularly important features making it desirable for aircraft applications--high discharge rates (up to 30 times its ampere-hour rating) and a high-energy-to-weight ratio (up to 56 watt-hours per pound). Other important features include its relatively constant voltage over most of the discharge period, long shelf life, ability to endure shock and vibration, and minimal gas expulsion.

Disadvantages of the silver-zinc battery include high relative cost (2.8 watt-hours per dollar compared to 45 and 8.5 watt-hours per dollar for lead-acid and nickel-cadmium batteries respectively), poor low-temperature characteristics, low cycle life, and sensitivity to overcharge.

The transition from the lead-acid storage battery to the newer silver-zinc battery in many aircraft applications, plus its unusual characteristics which completely differ from the older lead-acid system, makes it necessary for maintenance personnel to familiarize themselves with the silver-zinc battery. Maintenance personnel should follow the maintenance procedures outlined in manufacturer's data, if available. If this data is not available, the general procedures outlined in this article may be used.

Table 1 contains general information required for most servicing and maintenance operations.

ACCESSION for	
NTIS	White Section <input checked="" type="checkbox"/>
DDC	Buff Section <input type="checkbox"/>
UNANNOUNCED	
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
END / or SPECIAL	
X	

TABLE I. Characteristics and Requirements of Silver-Zinc Batteries in Current Use for Aircraft Applications

Item	Description	Manufacturer's Specification				
		6000-1(V)* 6000-2(V)* 6000-3(V)* 6000-4(V)*	6000-5(V)	6000-6(V)	6000-7(V)	
		6000-8(V)	6000-9(V)	6000-10(V)	6000-11(V)	
Military Standard (FAR 100-107, Part 107)						
1	CAPACITY (ampere-hours)					
1.1	MILITARY	12	30	50	75	100
1.2	COMMERCIAL	15	50	80	-	100
2	VOLT. GR. (gross) (volts)	24	24	24	24	24
2.1	NOMINAL DISCHARGE VOLTAGE (1.5 volts x number of cells)	21 - 22	21 - 22	21 - 22	21 - 22	21 - 22
FILLING AND SOAKING						
3	ELECTROLYTE QUANTITY (cubic centimeters per cell)	60	125	130	-	100
4	MINIMUM SOAKING TIME (hours)	72	72	72	72	72
FORMATION CHARGE(S)						
5	CHARGING RATE, CONSTANT-CURRENT (amperes)	1.0	3.0	4.0	5.0	5.0
5.1	CHARGING RATE, MODIFIED-CONSTANT-POTENTIAL (amperes)	4.0	15.0	25.0	37.5	50.0
Note: See 1001 - 1004 for series limiting resistor value						
6	CHARGING END VOLTAGE (battery) (volts)	20.0 - 23.5	20.0 - 23.5	20.0 - 23.5	20.0 - 23.5	20.0 - 23.5
6.1	CHARGING END VOLTAGE (cell) (volts max.)	2.05	2.05	2.05	2.05	2.05
7	MINIMUM ACCEPTABLE FORMATION INPUT CAPACITY (amp.-hour.)	15.0	39.0	65.0	97.5	100.0
FORMATION DISCHARGE(S)						
8	DISCHARGE 2-HOUR RATE (amperes)	6.0	15.0	25.0	45.0	50.0
8.1	END VOLTAGE (1.1 volts x number of cells)	15.4	15.4	15.4	15.4	15.4
9	DRAIN DISCHARGE RATE (amperes)	5.0	5.0	5.0	5.0	5.0
9.1	END VOLTAGE (battery) (volts)	2 - 3	2 - 3	2 - 3	2 - 3	2 - 3
MAINTENANCE CHARGE(S)						
10	CHARGING RATE, CONSTANT-CURRENT (amperes)	1.0	3.0	4.0	5.0	5.0
10.1	INITIAL CHARGING RATE, MODIFIED-CONSTANT-POTENTIAL (amperes)	6.0	15.0	25.0	37.5	50.0
10.2	RESISTANCE TO LIMIT CURRENT TO 2-HOUR RATE FOR BATTERIES WITH TERMINAL VOLTAGE ABOVE 22 VOLTS (ohms)	1.0	0.4	0.14	0.16	0.12
10.3	WATTAGE FOR RESISTANCE VALUE OF 1001 ABOVE (watts)	33.00	90.00	150.00	225.00	300.00
10.4	RESISTANCE TO LIMIT CURRENT TO 2-HOUR RATE FOR BATTERIES FULLY DISCHARGED, TERMINAL VOLTAGE ABOVE 2 VOLTS (ohms)	4.00	1.73	1.4	0.09	0.02
10.5	WATTAGE FOR RESISTANCE VALUE OF 1003 ABOVE (watts)	153.00	590.00	650.00	975.00	1300.00
11	CHARGING END VOLTAGE (battery) (volts)	20.0 - 23.5	20.0 - 23.5	20.0 - 23.5	20.0 - 23.5	20.0 - 23.5
11.1	CHARGING END VOLTAGE (cell) (volts max.)	2.05	2.05	2.05	2.05	2.05
SERVICE DISCHARGE(S)						
12	DISCHARGE RATES FOR VARIOUS DISCHARGE TIMES (amperes)					
Note: Silver-zinc batteries may be discharged as required, but certain time-current limitations must be observed. As the discharge rate increases, the cycle life decreases.						
10.0-HOUR RATE						
12.1	1.2	3.0	5.0	7.5	10.0	
12.2	2.5	6.0	10.0	15.0	20.0	
12.3	4.0	10.0	17.0	24.0	30.0	
12.4	6.0	15.0	25.0	35.0	50.0	
12.5	11.0	27.0	45.0	60.0	100.0	
12.6	42.0	100.0	175.0	250.0	350.0	
12.7	72.0	100.0	200.0	300.0	450.0	
12.8	93.0	24.0	400.0	500.0	700.0	
12.9	160.0	300.0	675.0	1000.0	1500.0	
10.0-MINUTE RATE						
12.10	42.0	100.0	175.0	250.0	350.0	
12.11	72.0	100.0	200.0	300.0	450.0	
12.12	93.0	24.0	400.0	500.0	700.0	
12.13	160.0	300.0	675.0	1000.0	1500.0	
5.0-MINUTE RATE						
12.14	42.0	100.0	175.0	250.0	350.0	
12.15	72.0	100.0	200.0	300.0	450.0	
12.16	93.0	24.0	400.0	500.0	700.0	
12.17	160.0	300.0	675.0	1000.0	1500.0	
2.5-MINUTE RATE						
12.18	42.0	100.0	175.0	250.0	350.0	
12.19	72.0	100.0	200.0	300.0	450.0	
12.20	93.0	24.0	400.0	500.0	700.0	
12.21	160.0	300.0	675.0	1000.0	1500.0	
1.5-MINUTE RATE						
12.22	42.0	100.0	175.0	250.0	350.0	
12.23	72.0	100.0	200.0	300.0	450.0	
12.24	93.0	24.0	400.0	500.0	700.0	
12.25	160.0	300.0	675.0	1000.0	1500.0	
0.5-MINUTE RATE						
12.26	42.0	100.0	175.0	250.0	350.0	
12.27	72.0	100.0	200.0	300.0	450.0	
12.28	93.0	24.0	400.0	500.0	700.0	
12.29	160.0	300.0	675.0	1000.0	1500.0	
0.25-MINUTE RATE						
12.30	42.0	100.0	175.0	250.0	350.0	
12.31	72.0	100.0	200.0	300.0	450.0	
12.32	93.0	24.0	400.0	500.0	700.0	
12.33	160.0	300.0	675.0	1000.0	1500.0	
0.125-MINUTE RATE						
12.34	42.0	100.0	175.0	250.0	350.0	
12.35	72.0	100.0	200.0	300.0	450.0	
12.36	93.0	24.0	400.0	500.0	700.0	
12.37	160.0	300.0	675.0	1000.0	1500.0	
0.0625-MINUTE RATE						
12.38	42.0	100.0	175.0	250.0	350.0	
12.39	72.0	100.0	200.0	300.0	450.0	
12.40	93.0	24.0	400.0	500.0	700.0	
12.41	160.0	300.0	675.0	1000.0	1500.0	
0.03125-MINUTE RATE						
12.42	42.0	100.0	175.0	250.0	350.0	
12.43	72.0	100.0	200.0	300.0	450.0	
12.44	93.0	24.0	400.0	500.0	700.0	
12.45	160.0	300.0	675.0	1000.0	1500.0	
0.015625-MINUTE RATE						
12.46	42.0	100.0	175.0	250.0	350.0	
12.47	72.0	100.0	200.0	300.0	450.0	
12.48	93.0	24.0	400.0	500.0	700.0	
12.49	160.0	300.0	675.0	1000.0	1500.0	
0.0078125-MINUTE RATE						
12.50	42.0	100.0	175.0	250.0	350.0	
12.51	72.0	100.0	200.0	300.0	450.0	
12.52	93.0	24.0	400.0	500.0	700.0	
12.53	160.0	300.0	675.0	1000.0	1500.0	
0.00390625-MINUTE RATE						
12.54	42.0	100.0	175.0	250.0	350.0	
12.55	72.0	100.0	200.0	300.0	450.0	
12.56	93.0	24.0	400.0	500.0	700.0	
12.57	160.0	300.0	675.0	1000.0	1500.0	
0.001953125-MINUTE RATE						
12.58	42.0	100.0	175.0	250.0	350.0	
12.59	72.0	100.0	200.0	300.0	450.0	
12.60	93.0	24.0	400.0	500.0	700.0	
12.61	160.0	300.0	675.0	1000.0	1500.0	
0.0009765625-MINUTE RATE						
12.62	42.0	100.0	175.0	250.0	350.0	
12.63	72.0	100.0	200.0	300.0	450.0	
12.64	93.0	24.0	400.0	500.0	700.0	
12.65	160.0	300.0	675.0	1000.0	1500.0	
0.00048828125-MINUTE RATE						
12.66	42.0	100.0	175.0	250.0	350.0	
12.67	72.0	100.0	200.0	300.0	450.0	
12.68	93.0	24.0	400.0	500.0	700.0	
12.69	160.0	300.0	675.0	1000.0	1500.0	
0.000244140625-MINUTE RATE						
12.70	42.0	100.0	175.0	250.0	350.0	
12.71	72.0	100.0	200.0	300.0	450.0	
12.72	93.0	24.0	400.0	500.0	700.0	
12.73	160.0	300.0	675.0	1000.0	1500.0	
0.0001220703125-MINUTE RATE						
12.74	42.0	100.0	175.0	250.0	350.0	
12.75	72.0	100.0	200.0	300.0	450.0	
12.76	93.0	24.0	400.0	500.0	700.0	
12.77	160.0	300.0	675.0	1000.0	1500.0	
0.00006103515625-MINUTE RATE						
12.78	42.0	100.0	175.0	250.0	350.0	
12.79	72.0	100.0	200.0	300.0	450.0	
12.80	93.0	24.0	400.0	500.0	700.0	
12.81	160.0	300.0	675.0	1000.0	1500.0	
0.000030517578125-MINUTE RATE						
12.82	42.0	100.0	175.0	250.0	350.0	
12.83	72.0	100.0	200.0	300.0	450.0	
12.84	93.0	24.0	400.0	500.0	700.0	
12.85	160.0	300.0	675.0	1000.0	1500.0	
0.0000152587890625-MINUTE RATE						
12.86	42.0	100.0	175.0	250.0	350.0	
12.87	72.0	100.0	200.0	300.0	450.0	
12.88	93.0	24.0	400.0	500.0	700.0	
12.89	160.0	300.0	675.0	1000.0	1500.0	
0.00000762939453125-MINUTE RATE						
12.90	42.0	100.0	175.0	250.0	350.0	
12.91	72.0	100.0	200.0	300.0	450.0	
12.92	93.0	24.0	400.0	500.0	700.0	
12.93	160.0	300.0	675.0	10		

1.1 Operation

The exact chemical reactions that take place within a silver-zinc cell during charge and discharge are still imperfectly understood. However, during discharge the process that occurs can be described as the simultaneous reduction of the positive active material to silver, and oxidation of the negative active material to zinc-oxide, resulting in an exchange of oxygen (or hydroxyl groups) from the positive to negative electrode which produces an emf between the cell terminals. This process is simply reversed during the charging portion of the cycle.

The electrolyte acts only as a carrier during charge and discharge and does not take an active part in the chemical reaction. Consequently, its specific gravity does not undergo an appreciable change.

2. MAINTENANCE AND SERVICING

2.1 Unpacking and Inspection

When a battery is unpacked, a thorough inspection should be made to insure that no damage occurred during shipment.

Inspect the shipping container, as well as the battery, to make certain that the battery or cells have not suffered possible damage. Check to see if any liquid (if the battery was shipped wet) has spilled into the shipping container. This may indicate signs of a damaged cell.

Check all electrical connections for tightness. Test all screws and nuts on all terminals to insure tightness.

Silver-zinc batteries are equipped with special vent plugs which permit gasses to escape from the cells. Check to insure that these vents are not obstructed in any manner which will interfere with their operation. New batteries may be received with solid plugs which are used for shipping. If solid plugs have been used, remove them and install the vent plugs inside the small bag attached to the battery.

2.2 Determination of State of Charge

The state of charge of a silver-zinc battery may be estimated by measuring the open-circuit voltage across the individual cell terminals after removing the battery case cover. This measurement can be made by using a voltmeter that reads accurately

to 0.01 volts, and should indicate between 1.82 volts and 1.86 volts per cell, which shows that the battery is charged to at least 70% of capacity. If the reading of any cell is below 1.82 volts, the battery requires further tests and maintenance to determine the reason for the low voltage. Similarly, an open-circuit battery terminal voltage of 25.6 volts or more for a 14 cell battery indicates the battery is at least 70% charged. However, a battery may have a terminal voltage in excess of 26.5 volts and still have a defective cell. Therefore, it is advisable that the terminal voltage of the individual cells be checked.

An estimation of the approximate state of charge of the silver-zinc battery may also be made under load conditions by discharging the battery at the 1-hour rate for 5 or more minutes and measuring the terminal voltage. If the terminal voltage measures less than 15.5 volts, the battery is considered as fully discharged. Note, however, that again this method may not detect defective or unbalanced cells. Should unbalanced cells continue to be used, they may reverse polarity and cause loss of capacity or battery failure.

Specific gravity measurement of the potassium hydroxide electrolyte used in the silver-zinc battery cannot be used to determine the state of charge.

2.3 Servicing with Electrolyte

2.3.1 Filling a New Battery

The silver-zinc battery is usually shipped in a dry condition. Only the special electrolyte furnished in the filling kit provided with each new battery should be used. Some battery types may use electrolytes containing special additives and other electrolytes, if used, may degrade the battery. The electrolyte must be kept in a closed alkali-resistant container, or it will absorb carbon dioxide from the air and deteriorate. The filling kit contains detailed instructions for filling and should be followed in detail. If these instructions are not enclosed when the battery is received, the following instructions may be used.

NOTE

Batteries that will not be used within 30 days should be stored in the dry state.

Never completely fill a silver-zinc cell with electrolyte--a very specific quantity of potassium-hydroxide electrolyte solution must be placed in each cell. Either an excess or a deficiency of electrolyte will be detrimental to the characteristics of the battery. Periodically, the electrolyte in each cell must be leveled. Part numbers of electrolyte filling kits and the quantities of electrolyte applicable to the cells of each type of silver-zinc battery in current use are shown in Table 2.

MANUFACTURER	ESB	YARDNEY	YARDNEY	YARDNEY	YARDNEY	YARDNEY
Battery Part Number	SK-7684	3134-4	3134-6	5805	6490	8073
Filling Kit P/N		5458	5458	6528	6570	6570
Quantity of Electrolyte per Cell	50 cc (1.7 oz)	60 cc (2 oz)	60 cc (2 oz)	125 cc (4.2 oz)	130 cc (4.4 oz)	130 cc (4.4 oz)

* No kit number. Electrolyte provided in large quantity containers.

TABLE 2

ELECTROLYTE QUANTITIES AND FILLING KITS

WARNING

The electrolyte is a strong solution of potassium-hydroxide that is alkaline and highly corrosive. It will cause serious burns if permitted to come in contact with the eyes or skin. Alkali-proof aprons, rubber gloves, and splash-proof goggles or face mask, shall be used during filling operations.

INTERNAL ANTIDOTES. Obtain medical attention at once. Give large quantities of water and a weak acid solution, such as vinegar, lemon juice or orange juice. Follow with white of egg, olive oil, starch water, mineral oil or melted butter.

EXTERNAL ANTIDOTES. Obtain medical attention at once. For the skin, wash the affected area with large quantities of water. Neutralize with vinegar, lemon juice or 5 percent solution of acetic acid and wash with water. For the eyes, wash with repeated amounts of water. Using an eye cup, wash with a mild solution of boric acid.

2.3.1.1 Filling Procedure

- a. In some cases, spacers and clamps are provided with each battery. Install and secure the spacer and clamp. Never move the battery without the clamp installed after electrolyte has been added. The clamp and spacer protects the battery from rupture if excessive swelling or internal pressures should develop.
- b. Remove battery cover.
- c. Remove and discard any tape covering the cell vent caps. Remove the vent caps and the sponge rubber plugs from the vent holes using tweezers. Make a sketch or notation of the location of the vent caps if different sizes are used for one or more cells. Save the vent caps, sponges, or other electrolyte trap assembly devices for reuse after placing electrolyte in cells.

- d. Remove the cap from an electrolyte bottle containing the proper amount of electrolyte for one cell.
- e. Screw the polyethelene filling cap provided with the filling kit, securely onto the electrolyte bottle.
- f. Insert the filling cap tip into the cell vent hole, twisting clockwise to insure a tight fit.
- g. Squeeze electrolyte bottle gently, maintaining pressure for a few seconds to prevent drawing electrolyte back into the bottle. Repeat this operation until all of the electrolyte in the bottle is transferred to the cell. If the electrolyte is repeatedly drawn back into the bottle, wait until the level in the cell decreases and then continue. Do not remove filling bottle from the cell until all the electrolyte is transferred.
- h. Remove the filling bottle and clean excess electrolyte from the cell vent hole using the vent cleaner provided. Insert the vent cleaner up to the knot into the cell vent hole and turn one complete revolution. Use a new vent cleaner for each cell.
- i. Remove any excess electrolyte from around the outside of the cell vent holes using a piece of cotton held with tweezers.
- j. Insert sponge rubber plug into vent hole, using tweezers, and press the vent cap over the vent.
- k. Remove filling cap from the empty bottle and install on another full bottle. Repeat steps d through j for the remaining 13 cells of the battery.

NOTE

Be sure to cap each cell, after it is activated with electrolyte, to prevent either skipping a cell or filling one twice. After all cells have been filled, wash three of the electrolyte bottles with water and air dry. These bottles will be required in the performance of electrolyte level adjustments.

After filling with electrolyte, allow each cell or battery to soak for a minimum period of 72 hours. During the first two hours of the soaking period, the battery should be placed on

its back (side opposite the terminal connectors). After two hours of soaking in this position, the battery must be returned to its upright position for the remaining 70 hours.

Batteries may be received in either the dry-unformed, or the dry-fully charged condition. If received in the dry-fully charged condition, after the electrolyte has been added and the battery is allowed to soak for 72 hours or more, the cell terminal voltages must be measured with a voltmeter accurate to 0.01 volts. If all cells measure 1.82 volts or more, the battery is ready for service. Batteries received in the dry-unformed condition, after the electrolyte has been added and allowed to soak for at least 72 hours and no more than 10 days, must receive formation changing.

2.3.2 Electrolyte Leveling

A silver-zinc battery should be removed from the aircraft at 60 day intervals and the electrolyte level of each cell adjusted using the appropriate maintenance kit for the battery type.

NOTE

Electrolyte is absorbed by the separators and active materials of the plates as the cells discharge. This causes an apparent reduction of electrolyte in the cell. It is mandatory that the battery be recharged prior to performing electrolyte leveling operations.

2.3.2.1 Leveling Procedure

- a. Remove battery cover and electrolyte trap assemblies.

NOTE

In some cases different sizes of trap assemblies are used for outside perimeter cells. Where different types of trap assemblies are used, mark the cells concerned. Save all vent trap assemblies for use after the leveling operation is completed.

- b. Using tweezers, remove sponge rubber plug in each vent, if present.
- c. Charge battery, observing all precautions on over-heating and overcharging.
- d. Using contents of battery maintenance kit, or items saved from filling kit received with battery, place rubber washer in metal bottle cap having ground-off hypodermic needle attached.
- e. Screw leveling cap securely onto empty filling bottle.
- f. Insert metal leveling cap into vent hole of first cell of battery until its cone-shaped top touches vent.
- g. Compress and then release filling bottle. If electrolyte level is too high, excess will be drawn up into filling bottle. If no electrolyte is drawn up into bottle when it is compressed and released, electrolyte level is too low. Put about 40 cc of distilled water into bottle, and repeat squeezing and releasing operation until no air bubbles are drawn into filling bottle. Electrolyte level of each cell must be adjusted by removing excess electrolyte or adding distilled water as described above. After all cell electrolyte levels are adjusted, replace sponge rubber plugs and vent caps, ensuring that any odd sized vent caps are replaced on same cells from which removed. Any sponge rubber plugs or vent caps saturated with electrolyte or clogged with white crystals should be replaced.
- h. Allow battery to rest for a minimum of 12 hours.
- i. After 12 hours, perform maintenance discharge until the terminal voltage drops to between 15 and 16 volts.

- j. Allow battery to cool for 2 to 4 hours.
- k. Recharge battery in accordance with maintenance charging procedures.
- l. Remove any electrolyte or corrosion with absorbent cotton or clean damp rag.
- m. Inspect and tighten intercell connector nuts to torque values for specific battery as specified in Table 1.
- n. After charging, rest battery for minimum of 8 hours; then measure the terminal voltage of each cell. All cells should have essentially equal voltages of 1.82 volts or greater.

2.4 Charging Methods and Procedures

The constant-current charging method is recommended for all silver-zinc battery formation and maintenance charging. The modified constant-potential charging method may be used in the absence of constant-current charging equipment, provided certain precautionary measures are taken to protect the battery. Automatic constant-current charging equipment specified for use with silver-zinc batteries should be used when available. Otherwise, the typical constant-current chargers are satisfactory, provided the charging operation is closely monitored and the proper charging current used.

Constant-potential charging should be avoided because of the inherent dangers involved. The silver-zinc battery has extremely low internal resistance. If a partially or fully discharged battery is charged by this method, the battery will draw very high initial currents, which may result in damage or degrading effects.

If possible, all charging should be accomplished at an ambient temperature between 60° and 90°F. The temperature of the battery, measured by a thermometer attached to an inter-cell connector (attached with modeling clay or other means), must never exceed 150°F during charging.

WARNING

While silver-zinc batteries do not generate harmful gases during normal charge and discharge operations, they do generate both oxygen and hydrogen gases during excessive overcharging. All vent caps and sponge-rubber plugs must be removed from the vent holes during charging operations. If electrolyte is forced from the vent holes, or if excessive gassing is evident, it is an indication of overheating, and the charging operation should be interrupted for at least 8 hours to allow the battery to cool.

2.4.1 Constant-Current Charging

The constant-current method is preferred and provides the best means of achieving and monitoring a normal charge input. The charging current is maintained constant by frequent manual adjustment of charger, or by automatic means if automatic chargers are used. Recommended constant-current charging rates for specific battery types in present use are given in Table 1.

Silver-zinc batteries are sensitive to excessive voltage during charging and may be damaged if the voltage exceeds 2.05 volts per cell. Therefore, it is necessary that the charger be cut off at a voltage slightly below this point. The cut-off voltage must not exceed 28.5 volts for a 14-cell battery. If manual equipment is used, the cell and battery terminal voltages must be checked frequently by manual means.

2.4.2 Modified Constant-Potential Method

During an emergency, a constant-potential source may be used, with a suitable rheostat or fixed resistor in series with the battery to limit initial surge currents. The charger voltage must be monitored and not allowed to exceed 28 volts. Representative resistance and wattage values for charging partially discharged batteries with terminal voltages in excess of 22 volts are given in Table 1 for presently used batteries. The resistance values given limit the initial surge of current to a 2-hour rate.

The value of resistance to limit the initial inrush of charging current to safe values may be calculated as follows:

- a. Measure battery open-circuit terminal voltage
- b. Determine the difference between the battery charger voltage and the open-circuit terminal voltage ($E_{Charger} - E_{Battery}$)
- c. The value of the limiting resistor required is

$$R = \frac{(E_{Charger} - E_{Battery})}{\text{maximum allowable current}} \text{ ohms}$$

The required power dissipation for the resistor is

$$P = I^2R \text{ watts}$$

For Example:	Charger voltage	28 volts
	Battery voltage	22 volts
	Battery Capacity	50 ampere-hours
	Maximum current (c/2)	25 amperes

$$R = \frac{E_{\text{charger}} - E_{\text{Battery}}}{\text{maximum allowable } I} = \frac{6}{25} = 0.24 \text{ ohms}$$

$$P = I^2R = (25)^2 \times 0.24 = 150 \text{ watts}$$

2.4.2.1 Charging Procedure for Discharged Battery having Terminal Voltage greater than 22 Volts

If it is determined that the battery open-circuit terminal voltage is greater than 22 volts proceed as follows to charge the battery:

- a. Adjust output voltage of constant-potential charger to a maximum of 28 volts without a load connected.
- b. Connect a rheostat or resistor, having the correct resistance and wattage ratings, in series with the battery to be charged (Table 1).
- c. Connect to charging source and charge for approximately 2 to 3 hours.
- d. Stop the charge.
- e. Insert a dc ammeter, which is set on 10-ampere scale, in series with the battery and resume charging.
- f. When the charging current drops to 0.4 ampere, the battery is considered fully charged.

2.4.2.2 Charging Procedure for Discharged Battery having Terminal Voltage less than 22 Volts

The modified constant-potential method is not recommended for a battery that has an open-circuit voltage below 22 volts. A battery, which has been completely drained, when placed on a modified constant-potential charge will draw extremely high currents during the initial part of the charge because of the large voltage difference between the battery and the charging source. If it is absolutely essential to charge a drained (completely discharged) battery by this method, a resistor with a much higher wattage and resistance rating must be used. Charging may proceed after the proper resistor has been connected in series with the battery and the charger voltage set to 28 volts. After charging for approximately 2 hours, stop the charge and remove the resistor. Replace the removed resistor with one that has the wattage and resistance values specified in Table 1, and resume charging. Complete charging by following Steps c through f above.

2.5 Formation Charging and Discharging

Formation charging applies to unformed batteries only. The constant-current method is recommended for formation charging, although the modified constant-potential method can be used provided the precautions noted previously are closely followed. For determining the activated life of a battery during later cell replacement, the date of battery activation should be stenciled on the battery case.

2.5.1 Formation Charge/Discharge Procedure

After the battery has been filled with electrolyte and soaked for at least 72 hours, but no longer than 10 days, it may start formation cycling. During the charge cycle, the temperature of the battery should not be permitted to exceed 150°F. If a thermometer is not available, the battery temperature may be estimated by touching the intercell connector; if the touch is uncomfortable, the battery is overheated.

a. First Formation Charge

Charge the battery at the constant-current rate shown in Table 1 for the specific battery type. While charging, monitor the ampere-hour input. Continue charging until the battery terminal voltage reaches 28 to 28.5 volts, or until 100% of rated capacity has been put into the battery. For example: If the charging rate for a 30 ampere-hour battery is 3 amperes, charging time will be approximately 10 hours before battery terminal voltage reaches 28 to 28.5 volts.

If the battery terminal voltage rises to 28 - 28.5 volts before 100% capacity is reached, rest the battery for 8 hours and then continue charge until 100% of ampere-hour capacity is reached within a final voltage of 28 to 28.5 volts. If electrolyte is forced out of the cell vent openings or if overheating is evident, interrupt the charge for 8 hours or more and check charger for proper output.

CAUTION

It is important that the battery terminal voltage not exceed 28.5 volts. Excessive heating and gassing, which occur above this voltage, will damage the battery.

b. First Formation Discharge

Discharge the battery at the current rate specified in Table 1 until the battery terminal voltage, while discharging, drops to between 15 and 16 volts. If automatic discharging equipment is used, set to the minimum end-voltage specified in the associated operating instructions.

c. Drain Discharge

After the first formation discharge, allow the battery to cool for a period of 2 to 4 hours. Discharge the battery at the 20-hour current rate (or as indicated in Table 1 for Drain Discharges) until the total battery terminal voltage drops to 2 to 3 volts. If automatic discharging equipment is being used, follow the operating instructions for this equipment.

Individual cell voltages must be checked frequently during discharge. At the first indication of cell voltage falling to zero, interrupt the discharge to prevent cell reversal. Short out the affected cell or cells with a suitable, flexible, shorting device. Continue this process until all 14 cells read zero.

CAUTION

If a cell is allowed to rest after it has been fully discharged without being shorted, it tends to restore itself. Cell terminal voltage should be rechecked if resting has occurred and additional discharging should be performed if the cell voltage is over 0.2 volts. Cell resistance is very low for silver-zinc batteries, and extremely high currents may flow if the cell is shorted, even when it is partially discharged. DO NOT SHORT CELLS THAT HAVE TERMINAL VOLTAGES OVER 0.2 VOLTS.

d. Second Formation Charge

Charge the battery while monitoring the ampere-hour input at the current rate indicated in Table 1 until the battery terminal voltage, while charging, reaches 28.0 to 28.5 volts; or charge the battery for the number of hours required to give 110% of nominal rated capacity. For example: If charge rate for a 30 ampere-hour battery is 3 amperes, time for 110% rated capacity would be 11 hours. If a battery terminal voltage of 28.0 to 28.5 volts is reached before the input is 110% of rated capacity, rest the battery for 8 hours; then continue the charge until a total input of 110% of rated capacity is attained within a final battery terminal voltage of 28.0 to 28.5 volts.

e. Second Formation Discharge

Discharge the battery as described in Step b for the first formation discharge and give the battery a drain discharge as specified in Step c.

f. Third Formation Charge

Charge the battery while monitoring the ampere-hour input (at the current rate indicated by Table 1) until the battery terminal voltage, while charging, reaches 28.0 to 28.5 volts. If this voltage is attained before the input reaches 130% of the rated capacity, rest the battery for 8 hours; then continue the charge until a total input of 130 to 150% of rated capacity is obtained with a final terminal voltage between 28.0 and 28.5 volts.

g. Ending the Formation Cycling

If a battery takes an input of 130% or more during the third formation charge, it shall be considered formed and ready for service. If the minimum input cannot be attained during the third formation cycle, the battery should be cycled for a maximum of two additional formation cycles. If, after the fifth formation charge, an input of at least 110% of the rated capacity is not attained, the battery is not serviceable.

2.6 Maintenance Charging

Maintenance charging applies to batteries that have been partly or completely discharged during service or in storage. Before performing the maintenance charge, discharge the battery as described under First Formation Discharge and Drain Discharge. After drain discharging, proceed with maintenance charging. No cell should be permitted to exceed 2.05 volts while charging. When automatic equipment is incorporated, it should be adjusted to cut off slightly before the cells reach 2.05 volts (28.5 volts).

Constant-current charging is recommended. If it is necessary to use modified constant-potential, the precautions listed for this method should be strictly followed. Maintenance charging rates are provided in Table 1, by battery types. Do not allow battery to overheat or overcharge.

The minimum number of ampere-hours required to charge the battery will be equal to 100% of its rated capacity before the battery terminal voltage reaches 28.0 to 28.5 volts. However, the battery may accept up to 130% of its rated capacity. If 100% of capacity cannot be recharged into the battery after a drain discharge, rest the battery for 8 hours and then continue charging. If the battery has not reached 100% input after 3 charging cycles, it is not serviceable.

The battery should be allowed to rest for 8 hours after maintenance charging; then, check all cell voltages. If any cell reads below 1.82 volts, the battery should be further checked for damaged or defective cells.

2.7 Discharging Silver-Zinc Batteries

Appropriate load banks or resistances may be used to discharge batteries when automatic equipments are not available. Although silver-zinc batteries may be discharged at the 1-hour rate until the terminal voltage drops to approximately 15.4 volts (1.1 volts per cell), the 2-hour discharge rate is recommended (listed in Table 1 for each battery type). Discharging

at the 1-hour rate or higher is at the risk of overheating the battery. If it is desirable to drain-discharge (fully discharge) the battery, the load should be readjusted when the terminal voltage reaches 15 to 16 volts, so that the discharge current will be 5 amperes or less, and the discharge continued. The cell voltages must be frequently monitored after the battery voltage drops below 15.4 volts to prevent reversal. Follow the procedures and precautions of Step c under Formation Charging and Discharging for drain discharging.

2.8 Cell Replacement

If the battery is being serviced because of low voltage in an individual cell (i.e., below 1.82 volts), then the possible need for cell replacement exists. Drain discharge the battery as described under Steps b and c of Formation Charge and Discharge. Recharge the battery and allow it to set for 48 hours. Then check the voltage of each cell using a voltmeter accurate to 0.001 volts. Each cell should indicate a minimum open circuit voltage of 1.82 volts. If any cell reads below 1.82 volts, the cell must be replaced.

NOTE

Replacements for defective cells shall have the same approximate activated life period as the battery in which they will be installed.

Mark the cell to be replaced and note the position of the positive and negative terminals. Drain discharge the battery and remove the defective cell.

2.8.1 Preparing New Replacement Cell

Either a new cell or a used cell may be selected as a replacement. If a new cell is selected it must be filled with electrolyte and formed prior to being inserted into the battery. A new cell should only be used as a replacement in batteries having an activated life of less than 3 months.

Prepare a new unformed cell as follows:

1. Fill cell with electrolyte as described in electrolyte filling procedure.
2. Restrain wide sides of cell between two blocks of wood, and place clamps or tape tightly around wood blocks to prevent cell from swelling.
3. Form cell in accordance with procedures under Formation Charge and Discharge. Maximum voltage while on charge shall be 2.0 to 2.05 volts. Formation discharge shall be stopped when cell voltage drops to 1.07 and 1.20 volts. Drain discharge at 5 amperes until cell voltage drops to 0 - 0.2 volts. Install shorting cable across cell terminals until cell is to be installed in battery. Do not permit cell to reverse.

2.8.2 Preparing a Used Replacement Cell

If a used cell is selected for a replacement, the wet activated life must be comparable to the wet activated life of the battery in which it will be installed. If the selected cell has a wet activated life of no more than 1 month longer than the parent battery, it may be used safely, provided it passes the following test procedures:

1. Restrain the wide sides of the cell between two blocks of wood and place clamps or tape tightly around wood blocks to prevent cell from swelling.
2. Charge cell in accordance with procedures outlined under maintenance charging, except that maximum voltage while on charge shall be 2.0 to 2.05 volts for an individual cell.
3. Discharge cell at no more than 2-hour rate until cell voltage falls to 1.2 - 1.3 volts, while monitoring capacity output, minimum capacity output shall be 100% of rated capacity.
4. If minimum capacity output of 100% is obtained, drain discharge cell.
5. If minimum output of 100% capacity is not obtained in proceeding step, cell should not be used as replacement, and another cell must be selected.

2.8.3 Replacing a Cell

The following procedures should be followed when replacing defective cells in the silver-zinc battery:

1. Remove nuts and intercell connectors from cell or cells marked for replacement.
2. Remove defective cell or cells from parent battery.
3. Examine cell when it is removed to determine whether spacers are mounted on it. If so, spacers must be mounted on replacement cell in exactly same positions. (Spacers and cement are included in field repair kits for battery being repaired.)
4. Insert replacement cell into battery. Ensure that position of positive and negative terminals of replacement cell or cells is same as that of cell removed. Positive terminal of cell is marked with red line, also red sleeves are usually over individual wire connections to positive plates inside the cell.
5. Replace intercell connectors and top nuts. Tighten nuts to torque value recommended for specific battery as listed in Table 1.
6. Recharge battery in accordance with maintenance charging procedures.